Jurnal Kejuruteraan SI 4(2) 2021: 39-44
https://doi.org/10.17576/jkukm-2021-si4(2)-06

High Tensile Bollard Structure Using Macro Synthetic Fiber
(Tiang Pendek Bertegangan Tinggi Menggunakan Fiber Sintetik Kasar)

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Received 19 March 2021, Received in revised form 21 May 2021
Accepted 30 September 2021, Available online 31 October 2021

ABSTRACT

The usage of bollard is very important in protecting buildings. It can prevent vehicles from passing through the building. But the public now is less sensitive about the use of bollards. They assume the use of bollard is wasteful and for aesthetic only. Therefore, most buildings did not install bollards to protect the building. Besides that, there are also mounted bollards installed that are inappropriate to that place. For example, some bollards installed around buildings are not concrete type that can withstand strong impacts. Furthermore, some important and historic buildings need to install an explosive-proof type of bollard as building protection. The methods used for this research were non-destructive test and destructive test. Non-destructive test is slump test and destructive tests are compression test, tensile test, flexural test, and air blast test. Seven mix were used and tested in this research. From the compression test result, it shows that concrete mixed with 0.5% of macro synthetic is much stronger than control sample and other mixtures. From the tensile test, it shows that the control sample of the concrete achieved tensile strength of 3.48 N/mm² while the mixed concrete with 0.5 % mix of macro synthetic fiber gave higher tensile strength. The flexural test shows that the concrete mixed with percentage ratio of 0.5%, 1.0%, and 1.5% of macro synthetic fiber gave higher strength than the control sample which is only 2.77 N/mm². Based on experiments that have been carried out, it can fulfil objective one, which is to evaluate the type of blast safety for building envelope with the concrete bollard grade 30. Quality of concrete in terms of strength, tensile, and flexure of the proposed material with 0.5% of macro synthetic fiber can produce the same quality and meets the quality grade C30 concrete.

Keywords: Bollard; high-tensile concrete; synthetic fiber

ABSTRAK

Penggunaan tiang pendek (bollard) adalah sangat penting dari segi keselamatan bangunan. Ianya dapat menghalang kenderaan daripada melepasi terus ke bangunan. Tetapi orang awam sekarang kurang peka dengan penggunaan bollard tersebut. Sesetengah orang memikirkan penggunaan bollard adalah satu pembaziran dan hanya untuk nilai estetika sahaja. Selain itu, terdapat juga bollard yang dipasang yang tidak bersesuaian dengan tempat tersebut. Tambahan pula, bangunan - bangunan penting dan bersejarah juga perlu dipasang bollard yang jenis tahan letupan untuk melindungi bangunan tersebut. Kaedah yang digunakan untuk kajian ini adalah ujian tanpa musnah dan ujian musnah. Ujian tanpa musnah ialah ujian runtuhan dan ujian musnah adalah ujian mampatan, ujian tegangan, ujian lenturan, dan ujian letupan udara. Tujuh campuran telah digunakan dan diuji dalam kajian ini. Daripada hasil mampatan, ia menunjukkan bahawa campuran konkrit dengan 0.5% daripada sintetik makro adalah lebih kuat daripada sampel kawalan dan lain-lain campuran. Daripada ujian tegangan, ia menunjukkan bahawa sampel kawalan konkrit mencapai kekuatan tegangan 3.48 N/mm² manakala konkrit campuran dengan 0.5% campuran serat sintetik makro memberi kekuatan tegangan yang lebih tinggi. Ujian lenturan menunjukkan bahawa campuran konkrit dengan nisbah peratusan 0.5%, 1.0%, dan 1.5% daripada gentian sintetik makro memberi kekuatan lebih tinggi daripada sampel kawalan yang hanya 2.77 N/mm². Berdasarkan eksperimen yang telah dijalankan, ia boleh memenuhi objektif iaitu *untuk menilai jenis keselamatan letupan menggunakan bollard konkrit gred 30. Kualiti konkrit dari segi kekuatan, tegangan, dan lenturan bahan yang dicadangkan dengan 0.5% daripada gentian sintetik makro mampu menghasilkan kualiti yang sama dan memenuhi C30 konkrit kualiti gred.*

Kata kunci: Tiang pendek; konkrit tegangan tinggi; fiber sintetik

INTRODUCTION

A bollard is a short post designed to guide traffic and protect from vehicle intrusions. It falls under permanent structure depending on the usage or design. Bollard can be casted in-situ or pre-fabricated. The materials can be made from reinforced concrete, steel, or composite. Bollards can be manufactured and installed to withstand significant vehicle impacts, but they can also be used as visual barriers. Bollards also have decorative elements to complement building and landscape designs.

Throughout history, bollards have been used in many applications, including road or boundary markings and mooring posts. Bollards are still used to manage vehicle traffic and protect pedestrians, buildings, and landscapes.

In Malaysia, the usage of bollards is more towards the barrier function, either not to allow vehicles to pass through the road shoulder or to divert vehicles to a certain direction. The materials normally being used is steel pole and reinforced concrete and has a cylinder type design with 600 mm height and 150 mm diameter.

Bollards also offer esthetical view and not designed to withstand high impact and high tensile. The installation of bollards need to be in the proper way so that the foundation can maintain the verticality of the structure.

OBJECTIVES

The main aim of this study is to provide high tensile bollard for building protective element. The objectives of this paper as follow:

1. To explore the usage of bollard in building design; and
2. To determine the optimum mix for high tensile composite concrete bollard.

METHODOLOGY

This study aims to provide the high tensile bollard structure to be used as a protection for building security. Therefore, the mixing design has to be determined. The composition of materials should be established. The characteristic of normal concrete is weak in compression and low in tensile. Due to the properties of concrete, the mix must be incorporated with the tensile materials support such as fiber.

The design of the concrete mix emphasizes the high impact load and safety for building envelope such as danger of malicious attacks carried out by vehicle borne improvised explosive devices. These bollards are an effective and unobtrusive solution to protect buildings and their occupants from malicious vehicle attacks.

To accomplish this goal, some bollards must be tested with explosive material and observe the effect it has on them. The methodology involved as follows:

1. Literature review - Review the previous research regarding the usage of the bollard and its properties. Also, materials to construct the bollard
2. Materials preparation - Select the materials that can contribute to enhancing the tensile strength. In this research, the concrete will be mixed with 0.5% - 3.0% of macro synthetic fiber.
3. Samples preparation - Bollards with 1000 mm height and 150 mm diameter will be casted using G30 concrete mix design. 30 samples with 6 variances of mix were prepared for the testing.
4. Lab testing - The samples will be tested for compression and tensile test. The standard related are Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (ASTM C39) and Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C496)
5. Field blast testing – Real-time blast testing were set up accordingly to the TM5-1300 standard using commercial explosives.

The air blast tests were conducted at the shooting range area so that the splash of concrete debris will not hit random people. The explosive charge was positioned in the centre of the bollards with cross section at a distance of 500 mm from the bollards. The distance was chosen because the reflected pressure then can be considered as a uniformly distributed load across the bollards surface. The explosive charge consisted of trinitrotoluene mix with emulsion as a sphere. The maximum mass of the explosive in this test is 3 kg.

LITERATURE REVIEW

In designing the high tensile concrete mix, the fibers may be made out of a number of different polymer materials. These include relatively low modulus fibers such as polypropylene and polyethylene, and high modulus fibers such as carbon and Kevlar. Low modulus fiber is needed in the mix because low modulus offers the characteristic of elasticity.

Synthetic fibers have seen the most extensive use even though it has been noted in the literature that fibers with a modulus of elasticity greater than concrete are required to increase the strength of the concrete (Bentur 2007). In addition, the bonding strength between synthetic fibers and concrete is relatively low, meaning that the ability to transmit stresses across a matrix crack through interfacial bond is limited (Bentur 2007). However, many of the readily available synthetic fiber materials also exhibit these issues and synthetic offers many other advantageous properties. Synthetic fiber can be easily worked to produce a fiber with a higher modulus of elasticity and tensile strength (Gregor-Svetec & Sluga 2005).

This is of limited concern for hybrid fiber reinforced concrete as a pull-out failure mechanism is desired and is most often exhibited (Minelli 2005). Also, synthetic fibers can be easily formed into a variety of shapes and sizes with different surface finishes (Wang et al. 1987). This improves bond properties (Choi et. al. 2012) and can be done at a low cost, since the fibers are roughly ten times less expensive by weight than glass fibers (Richardson 2005 & Mu et al. 2002).

More recently, the desire to use synthetic fibers as structural reinforcement has grown. To this end, macro-synthetic fibers have been developed (Altoubat et al. 2009). An example of such fiber is the macro synthetic fiber as shown in Figure 2.1. This macro synthetic fiber has a relatively high elastic modulus for polypropylene (10 000 MPa). The fiber is "stick-like" and consists of two filaments cross-linked along the fiber length. In addition, the surface of the fiber is embossed to create deformations that provide mechanical anchorage between the fiber and the concrete.

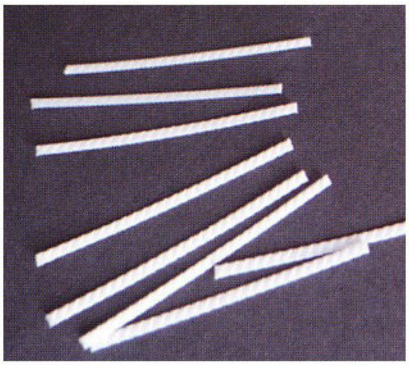

FIGURE 1. Example of macro synthetic fiber

Macro synthetic fibers, sometimes known as 'structural' synthetic fibers, are made from a blend of polymers and were originally developed to provide an alternative to steel fibers in some applications. Initially they were identified as a potential alternative to steel fibers in sprayed concrete, but increasing research and development showed that they had a role to play in the design and construction of ground-supported slabs and a wide range of other applications. It has been found that macro synthetic fibers may be used with a wide range of concrete strengths.

Hybrid reinforced concrete is not a new concept. Since old times, fibers were used in cementing construction materials. For example, in recent times, the asbestos fiber was extensively used in structural components like wall panels, roofs, and gates. In the early 1960's, the health risk of manufacturing and using asbestos fibers became apparent and alternative fibers were introduced as a replacement (Labib & Eden 2004).

This hybrid concrete will be the ingredients for high tensile concrete. It was designed to give around 30% of the tensile strength compared to normal concrete around 10%. It is suitable to use for constructing structure such as bollard.

A bollard is a short vertical post. Early bollards were for mooring large ships at dock, and they are still in use today. A typical marine bollard is produced in cast iron or steel and shaped somewhat like a mushroom which the enlarged top is designed to prevent mooring ropes from slipping off.

Today, the word bollard also describes a variety of structures used on streets, around buildings, and in landscaping. According to previous research, the first street bollards were actually cannons planted in the ground as boundary posts and town markers. When the supply of former cannons were used up, similarly shaped iron castings were made to fulfil the same functions. Bollards have since evolved into many varieties that are widely employed on roads, especially in urban areas, as well as outside supermarkets, restaurants, hotels, shops, government buildings, and stadiums.

Bollards are also used in the heavy industry and in commercial building management to protect assets. The bollard usually consists of a simple steel post anchored to concrete, cored into a hard surface, buried in the ground or secured on a self-locking taper or impact recovery system to protect the surrounding foundations when a bollard is struck. No doubt that the foundation must be strong to eliminates toppling.

The bollards protect utilities, machinery, buildings, or pedestrians from accidental collisions by vehicles, including passenger vehicles, transport trucking, and forklifts. As collisions can cause damage to vehicles, operators, or the bollards themselves, new bollards have been developed that absorb some of the impact energy, lessening the violence of the collision. Bollards are also useful in mixed-use public spaces, which support both pedestrian use and emergency or service vehicle use. The most expensive bollards can stop vehicles at speeds of about 80 km/h.

ANALYSIS AND RESULT

The data obtained from the test are recorded separately according to the type of concrete mixed. From the analysis, the most suitable water-cement ratio for the concrete grade C30 is 0.5. Consequently, all samples were run using the same water-cement ratio but differ in the ratio of the percent of the mixture of macro synthetic fiber.

Analysis of experiments are made based on the type of quality concrete grade C30 and is used as a reference for comparison with the concrete using macro synthetic fiber. This method can prove that using macro synthetic fiber as concrete admixture can improve the strength of the concrete.

The test results were recorded in 28 days because of the compress imposed compression test cubes. The result is in accordance with the percentage ratio mix of macro synthetic fiber to identify the impact of the concrete mixture used in the concrete mix. The results for the compression test are in 28 days as shown in Table 1.

TABLE 1. Table of compression test results for concrete samples at aged 28 day (cube)

Percent of Fiber (%)	No. Sample	Density (kg/m³)	Average Density (kg/m³)	Max load (kN)	Strength (N/mm²)	Average Strength (N/mm²)
0.0	1	2245.93		707.00	31.50	
(Control	2	2281.48	2275.56	709.00	31.50	31.43
Sample)	3	2299.26		705.00	31.30	
	1	2411.85		855.00	38.00	
0.5	2	2417.78	2394.07	908.00	40.35	39.48
	3	2352.59		902.00	40.08	
	1	2180.74		477.00	21.20	
1.0	2	2180.74	2204.44	505.00	22.40	21.26
	3	2251.85		454.00	20.17	
	1	2133.33		311.50	14.34	
1.5	2	2222.22	2172.84	310.40	13.79	14.22
	3	2162.96		311.60	14.52	
	1	2091.85		285.10	12.67	
2.0	2	2133.33	2110.62	267.10	11.87	12.19
	3	2106.67		273.00	12.03	
	1	2020.74		238.60	10.60	
2.5	2	2118.52	2079.01	265.20	11.78	11.21
	3	2097.78		246.60	11.26	
	1	2008.89		219.00	9.73	
3.0	2	1997.04	2006.91	205.80	9.14	9.47
	3	2014.81		212.60	9.55	

According to Table 1, concrete mixed with additional 0.5% of macro synthetic fiber gives the high value of compression which is 39.48 N/mm^2 compared to control sample. The additional compressive strength of 25% shows the macro synthetic fiber contributes to the strength of the concrete. However, the amount of macro synthetic fiber cannot be more than 0.5% because the compressive strength starts to decrease. It shows that the amount of micro synthetic fiber must be optimum.

Referring to the second objective of this research, the tensile strength of the bollard needs to be defined. The tensile test has been done at Civil Engineering Lab of UPNM. Table 2 shows the results of tensile test for all samples.

TABLE 2. Table of tensile test results for concrete samples at aged 28 day (Bollard, Cylinder)

Percent of Fiber (%)	No. Sample	Density (kg/m³)	Average Density (kg/m³)	Max load (kN)	Strength (N/mm²)	Average Strength (N/mm²)
0.0	1	577.13	73.00	3.55		
(Control	2	566.75	570.84	62.00	3.41	3.48
Sample)	3	568.64	67.60	3.49		
	1	535.63		229.10	12.96	

continue...

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0.5	2	584.67	569.90	215.20	12.17	12.38
	3	589.39		212.10	12.00	
	1	539.41		165.10	9.34	
1.0	2	545.06	541.92	167.30	9.46	9.64
	3	541.29		179.10	10.13	
	1	534.69		165.10	9.34	
1.0	2	545.06	541.92	167.30	9.46	9.64
	3	541.29		179.10	10.13	
	1	534.69		152.40	8.62	
1.5	2	538.46	536.58	152.10	8.60	8.60
	3	536.58		151.80	8.59	
	1	536.58		160.40	9.07	
2.0	2	529.03	530.60	124.70	7.05	8.02
	3	526.20		139.90	7.95	
	1	492.26		141.60	8.01	
2.5	2	501.69	497.13	120.90	6.84	7.30
	3	497.44		135.40	7.05	
	1	513.94		114.90	6.50	
3.0	2	505.46	508.92	111.60	6.31	6.60
	3	507.34		120.60	6.99	

According to Table 2, concrete mixed with additional macro synthetic fiber gives the additional value of tensile compared to control sample. It shows that macro synthetic fiber contributes to the tensile strength for concrete. The properties of fiber itself act as a tensile enhancement material.

However, looking at the practicality, concrete structure needs to achieve the designed compressive strength. In comparison with Table 1 and Table 2, 0.5% of macro synthetic fiber in concrete gives the high compression strength. Also, it offers the enhancement the tensile strength.

The data obtained shows the optimum content of the macro-synthetic fiber in the concrete mix. This mix has been used to produce the bollard for the field blast testing. The composite mix of macro synthetic fiber in concrete being mixed and poured into the cylinder mould. Five types of composite mix and a control sample were made in the lab lab and cured using plastic wrapping method. These six types of bollard was sent to Kem Kongkoi, Jelebu, Negeri Sembilan, Malaysia to perform the blast test. The blast test was conducted in normal environment temperature with normal humidity. The result shows there were no cracks and no damages for hybrid concrete bollard with 0.5% of macro synthetic fiber.

As conclusion, concrete mixed with additional 0.5% of macro synthetic fiber is the optimum content for the concrete bollard. The percentage referring the weight of cement in the mix design.

CONCLUSION

The usage of bollard is very important in protecting buildings. It can prevent vehicles from passing through to the building. But the public now is less sensitive about the use of bollards. They assume the use of bollard is just for esthetic. Therefore, most buildings do not install the bollards. Besides that, there are also mounted bollards installed that are not suitable to that place. The aim of this study is to provide high tensile bollard for building protective element. This study is beneficial to the development of bollard design. The design of bollard can be emphasized in malicious attacks carried out by vehicle borne improvised explosive devices. These bollards are an effective and unobtrusive solution to protect buildings and their occupants from malicious vehicle attacks. This study focuses on the impact of the explosive material to the design of the bollard. To accomplish this goal, some bollards must be tested with explosive materials and observe the effect on them. From this research, the usage of macro synthetic fiber with optimum content contributes to the enhancement of the concrete properties.

ACKNOWLEDGEMENTS

This research was supported by Short Term Grant, UPNM (UPNM/2016/GPJP/3/TK/2). We thank our colleagues from UPNM who provided insight and expertise that greatly assisted the research.

DECLARATION OF COMPETING INTEREST

None

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